Robotics Research Technical Report

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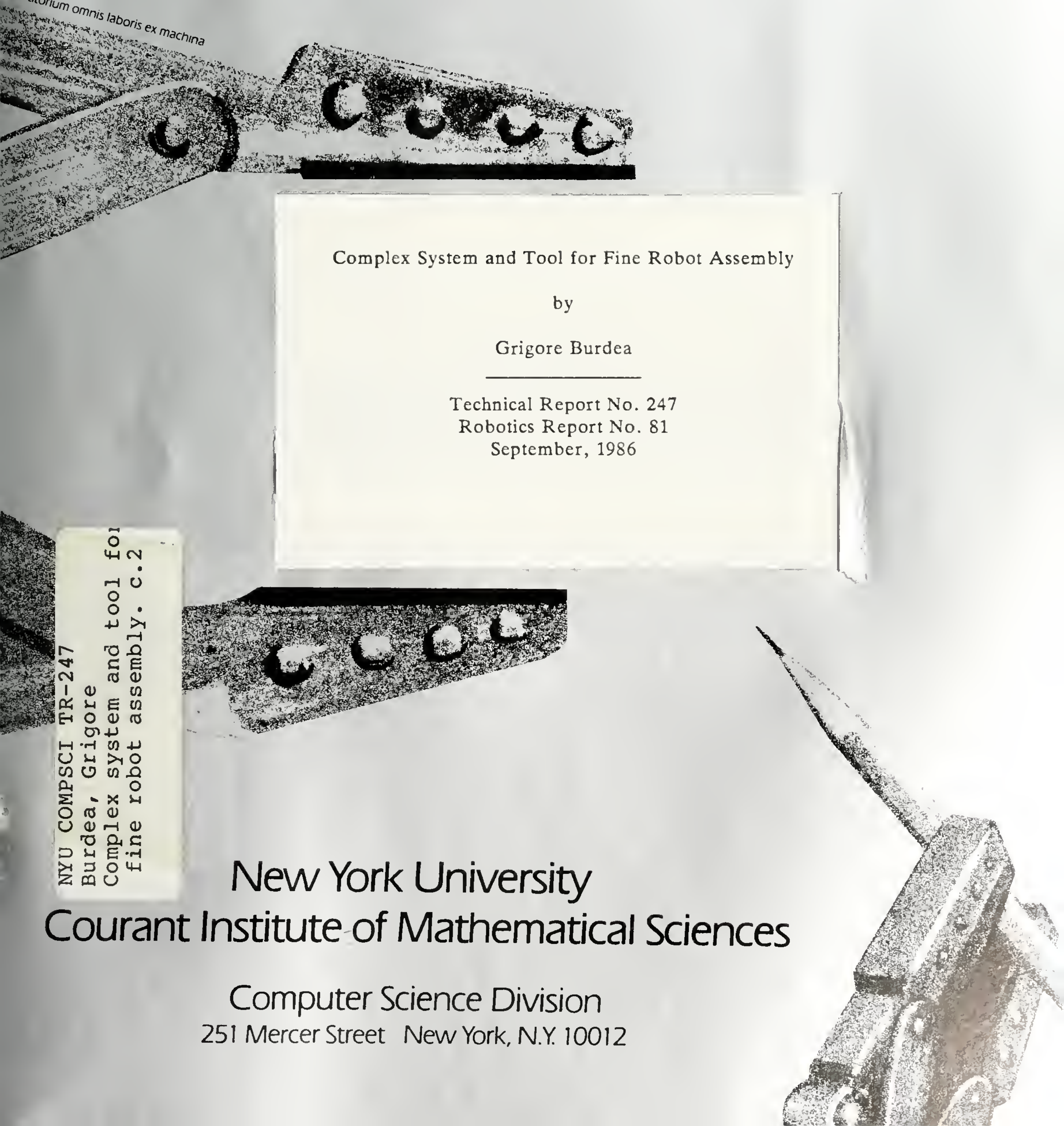

Complex System and Tool for Fine Robot Assembly

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Grigore Burdea

Technical Report No. 247
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September, 1986

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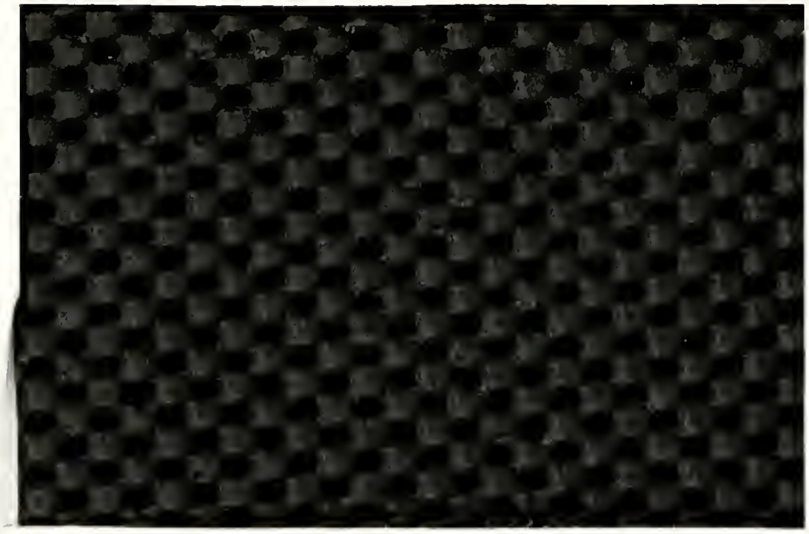

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Work on this paper has been supported by Office of Naval Research Grant N00014-82-K-0381, National Science Foundation CER Grant DCR-83-20085, and by grants from the Digital Equipment Corporation and the IBM Corporation.

Complex System And Tool For Fine Robot Assembly

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ABSTRACT

A complex robotics system using vision, tactile sensors and external tools is used to assemble objects of variable shape (jig-saw puzzle pieces) and orientation. Control of the process is shared between two computers, one used for vision and the other for robot control. Partial results are presented. This is a thesis proposal.

July 1986

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Complex System And Tool For Fine Robot Assembly [2]

Grigore Burdea [3]

1. Introduction

Present industrial robots can perform repetitive work with great accuracy and speed on a continuous basis [1]. However, despite these advantages, these robots are very limited in the type of work that they can perform [2]. Their load/weight ratio is very poor, being about an order of magnitude less than that of a worker. Their ability to do batch jobs is limited by a lack of good, inexpensive, commercially available end effectors and sensory equipment, both of which are needed to perform assembly work that employs adaptive control. In addition, present vision systems are too slow for real-time robot control, due in part to the enormous amount of computation required to process an image. This limits industrial application [3], but the situation is improving due to new super fast chips, parallel processing used in dedicated hardware, and the development of new general purpose vision systems.

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[2] Work on this project has been supported by Office of Naval Research Grant N00014-82-K-0381, National Science Foundation CER grant DCR-83-20085, and by grants from Digital Equipment Corporation and IBM Corporation.

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2. The purpose of this project

The main aim of this project is to implement and demonstrate a capability to assemble variable and complex shaped parts with relatively small tolerances. This is a substantially more demanding task than the "peg in a hole" problem treated in the literature [4],[5], due to the complex contour of the parts to be assembled, which are wooden jig-saw puzzle pieces.

Previous work by Edith Schonberg and Haim Wolfson at NYU Robotics Laboratory developed algorithms for simulated jig-saw puzzle assembly using a vision system. In their work, the puzzle pieces are initially digitized via a vision system, and a puzzle solution is obtained. This solution is stored in memory and can be displayed graphically (see Fig. 1, Assembled jig-saw puzzle). However, due to small vision system errors and to the fact that only the 2-D contour of the puzzle pieces is used (and not the image actually present on the puzzle), frequent small position errors occur in the solution.

This thesis will study the problems of actual physical assembly of jig-saw puzzles. The small errors which Schonberg and Wolfson could ignore are expected to prove central to our work. We propose to use puzzle pieces because they pose a significant challenge to mechanical assembly. Most of the difficulties already arise in attempting an automatic assembly of two puzzle pieces. Hence the first part of our effort will concentrate on development of techniques which hand this case well, then work will extend to the whole puzzle. In dealing with whole puzzles, the physical assembly procedures to be developed for this thesis may also have to cope with gross errors (since the Schonberg-Wolfson work will sometimes give several solutions which is unable to disanbiguate, so that the only way to validate may be through actual assembly [6]).

3. Installation

The assembly system to be developed will consist of a 7565 IBM robot, a vision system, tactile sensors, and an assembly tool. The design of this special tool and sensors constitutes a significant part of this project (see Fig. 2 which shows our manipulator system with vision equipment mounted, also Fig. 3 - Fine motion assembly installation). An existing vision system will be employed. This consists of a Fairchild CCD 4001 Robotics Camera, with a 256x256 sensor array, and a VICOM image processor system, which manipulates a 512x512 array. The Fairchild camera allows the sensor head to be placed on the robot arm, while the rest of the camera remains outside the work envelope. This will simplify installation and reduce the risk of damage to sensitive electronics in the main part of the camera. The camera will send the analogue image of a puzzle piece to the VICOM which digitizes it and displays the boundary and the corners of the puzzle piece on a color monitor. A MICROVAX host computer will control the whole vision process. Data obtained from the host computer will be sent to a SERIES 1 minicomputer which controls the robot arm (IBM 7565). The SERIES 1 will also control the operation of a special assembly tool used to handle the pieces. This tool is discussed in more detail in section 5.

4. Assembly-tool design considerations

The shape of the puzzle pieces and the characteristics of the 7565 gripper require a special tool to perform the assembly. This tool will use a vacuum cup, which has the advantage that contact would only occur at the top of the piece, minimizing the complexity of the operation. This approach is also useful because during the final stage of assembly, vacuum can be replaced by short pressure bursts to help force the piece into place [10]. The upper end of the tool will have a square shape to allow a flat contact surface with the gripper. A small hole (0.05" diameter) will help align the tool with the gripper, using the gripper's Light Emitting Diode (LED) sensor. Vacuum/pressure pipes and electrical circuitry for the tool will be routed through the robot vertical arm to clear the workspace of any unwanted external objects. These considerations led to the (tentative) design for the assembly tool presented in Fig. 7. Additional experiments will be necessary to determine the sensory requirements for assembly verification.

5. Fine assembly strategy

Once the tool is secured, the tip of the tool with its suction cup will approach the piece to be picked and descend along a vertical path. Motion will stop when the sum of the force readings on the tip sensors of the gripper exceeds a certain threshold. Once the tool is on top of the puzzle piece, the robots' force sensors will cause the robot controller to activate an external relay which in turn would start a vacuum pump. The air pressure sensor on the tool would then indicate via the robot controller when a desired vacuum is achieved which means that the puzzle piece is secured. The piece is then moved to the location of fine assembly with the necessary (raw) translation and rotation data previously obtained by the vision system (as presented in Chapter 6). In the actual assembly, the piece that is to be inserted will initially be inclined at about 15 degrees to the surface of the work table and pushed over the surface of the matching puzzle piece. Once the pieces to be assembled are in proper initial contact, with the compliance of the cup exercising a force on the horizontal puzzle piece (see Fig. 7), forces and moments will be measured by the force sensors on the gripper. When these readings decrease due to a hole in the horizontal piece, the piece that is held by the tool can be lowered into place by reducing the angle of inclination and/or stopping the vacuum pump. The last step associated with the assembly is to verify that the assembly is correct. This will be done by vision and force sensing. It is important to note that the range of the force sensors on the gripper is 0 to 100 Newtons, with one bit noise, which in force terms is equal to 0.15 Newtons (see Fig. 6 Force sensor indications with 0.15 Newtons random "jumps"). This noise therefore requires that the threshold values be lowered by 0.30 Newtons (for the worst case) and/or averaged over several consecutive readings. The range of forces used for fine assembly is 5-6 Newtons, which implies that the noise uncertainty is approximately 6%. The speed with which fine assembly is done will have to be quite small. In order to avoid vibrations or the loss of a picked piece, the speed would have to be of the order of 5% of the nominal speed of the 7565 robot.

6. Vision System software

An initial stage of the software will ascertain the position of each puzzle piece (see Fig. 4 - Data acquisition program called from 7565 controller and running on the host computer). This will be done by moving the camera in a search pattern. During the search, the camera will remain at a fixed distance above the work table, allowing the use of a fixed focal length lens and ensuring a sharp image. Detected pieces will be analyzed using the existing SHAPE program, whose output is a sampled curve. This information will then be used in the existing MATCH program to determine matching sides for corresponding puzzle pieces. This program will output the rotation necessary to align the two matching sides.

7. Communications

The host computer that coordinates the vision system and obtains the simulated assembly will run in an UNIX environment. This is a different operating system from that of SERIES 1 minicomputer (7565 controller), and communication between the two systems creates problems. To cope with this situation a 7565 Asynchronous Communications Support PRPQ program will be installed on the robot controller [11]. All communications will be done on a RS232 port available on SERIES 1, with data in ASCII format. The PRPQ program is not supported by IBM and it has to be "customized" for the needs of this project. All asynchronous communication techniques for interlacing the data transfers into a unique global program running on two different computers are still to be developed.

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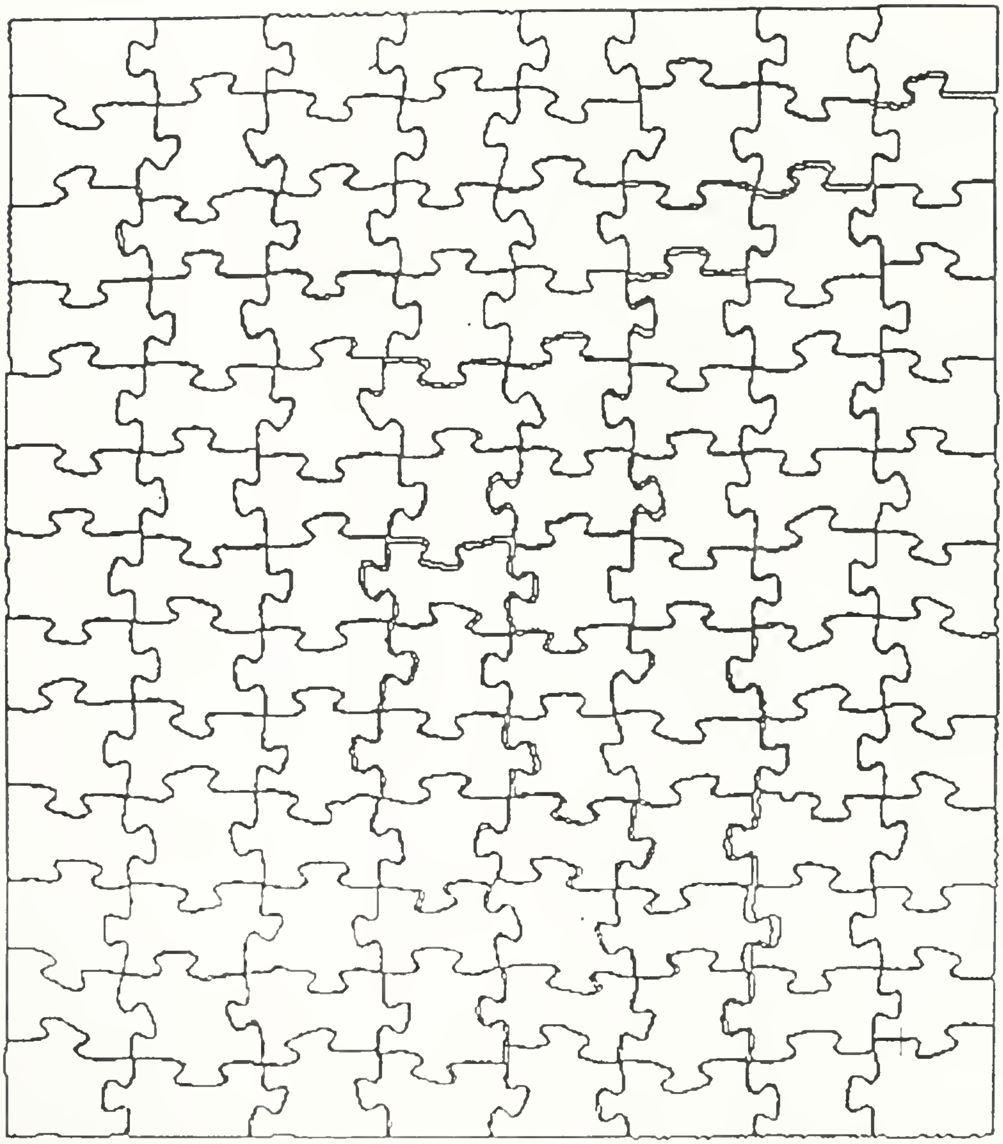

Figure 1. Assembled jig-saw puzzle

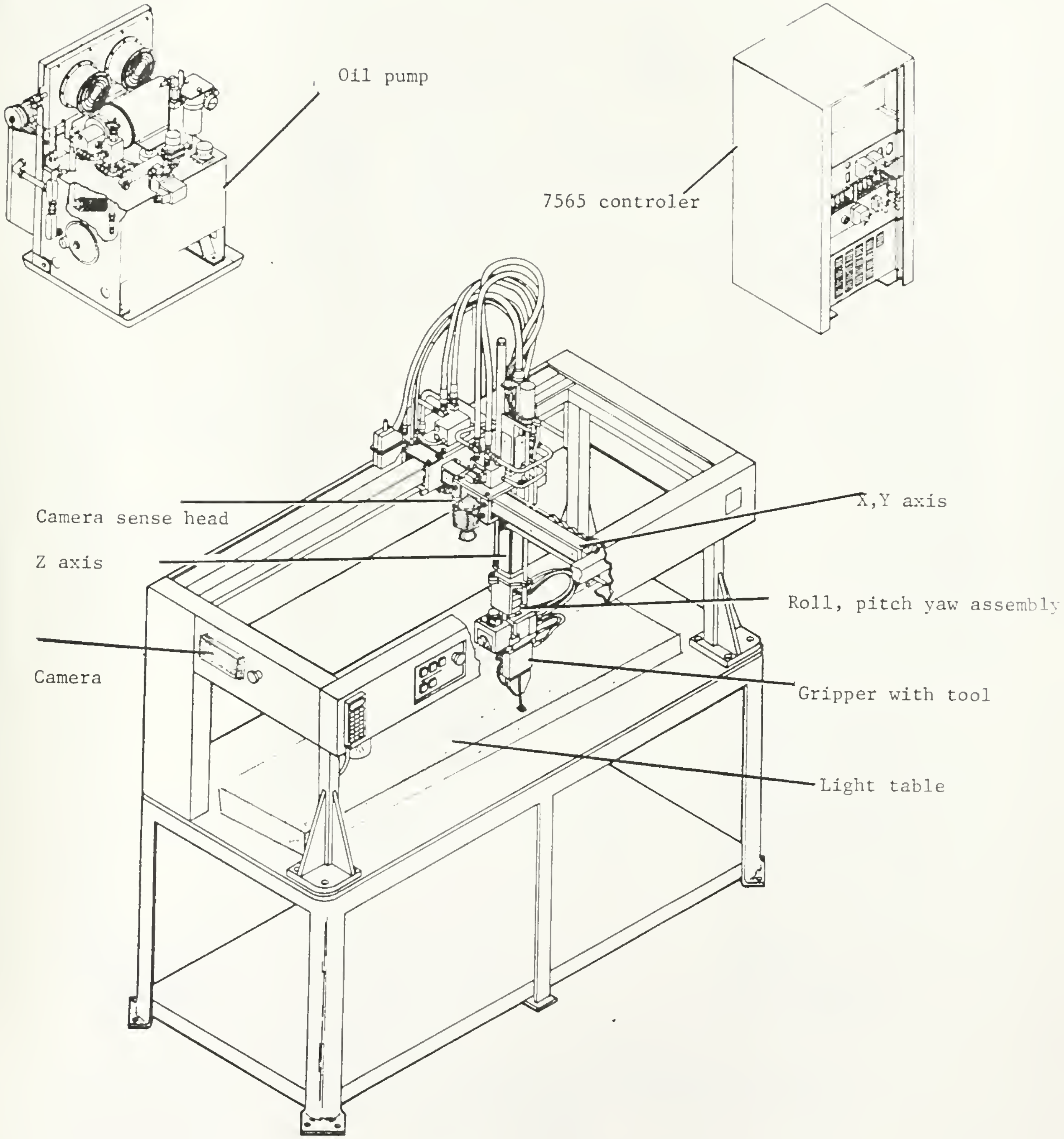

FIGURE 2 MANIPULATOR ASSEMBLY WITH VISION EQUIPMENT MOUNTED ON

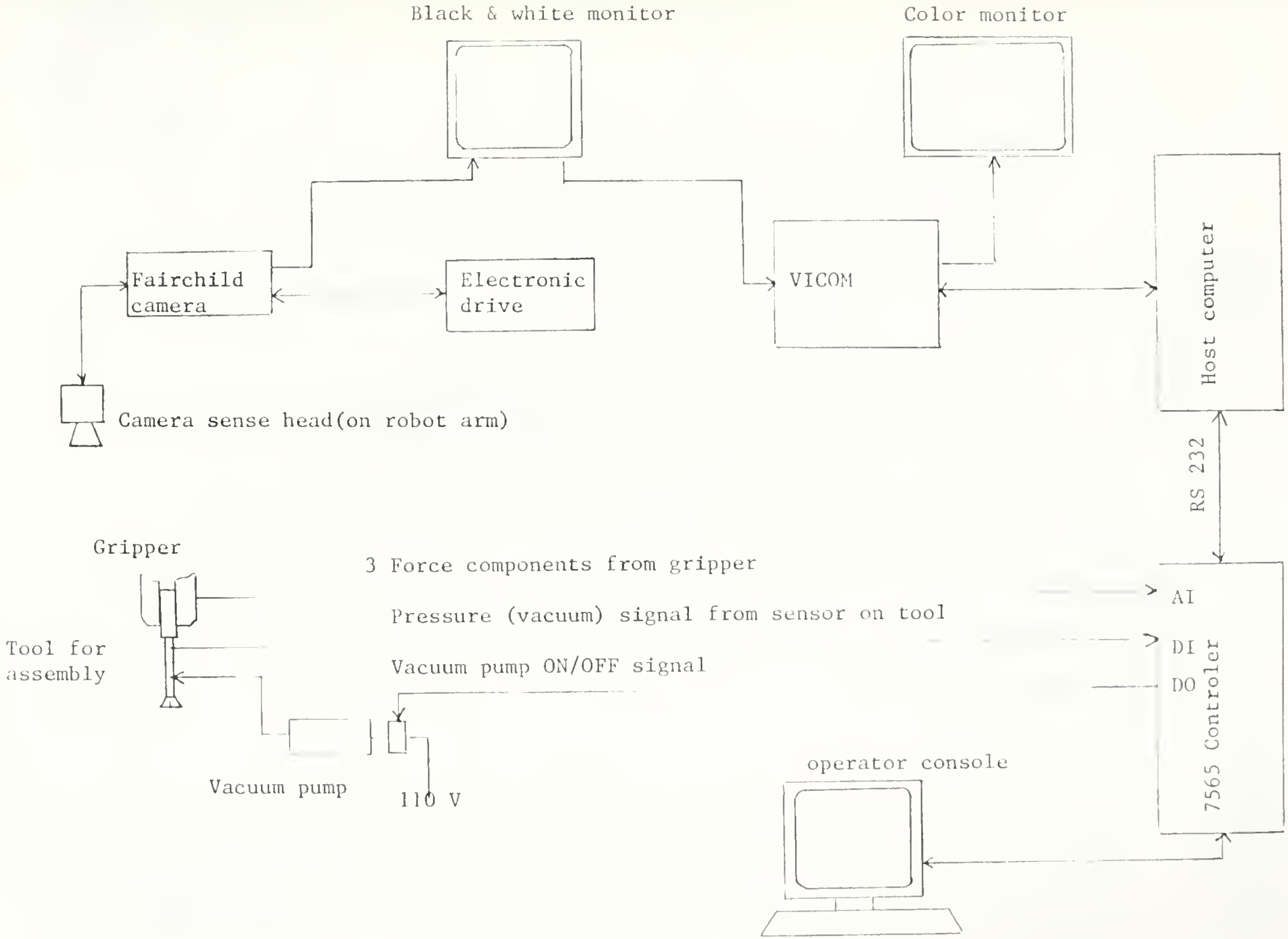

Fig. 3 Fine motion assembly robot installation

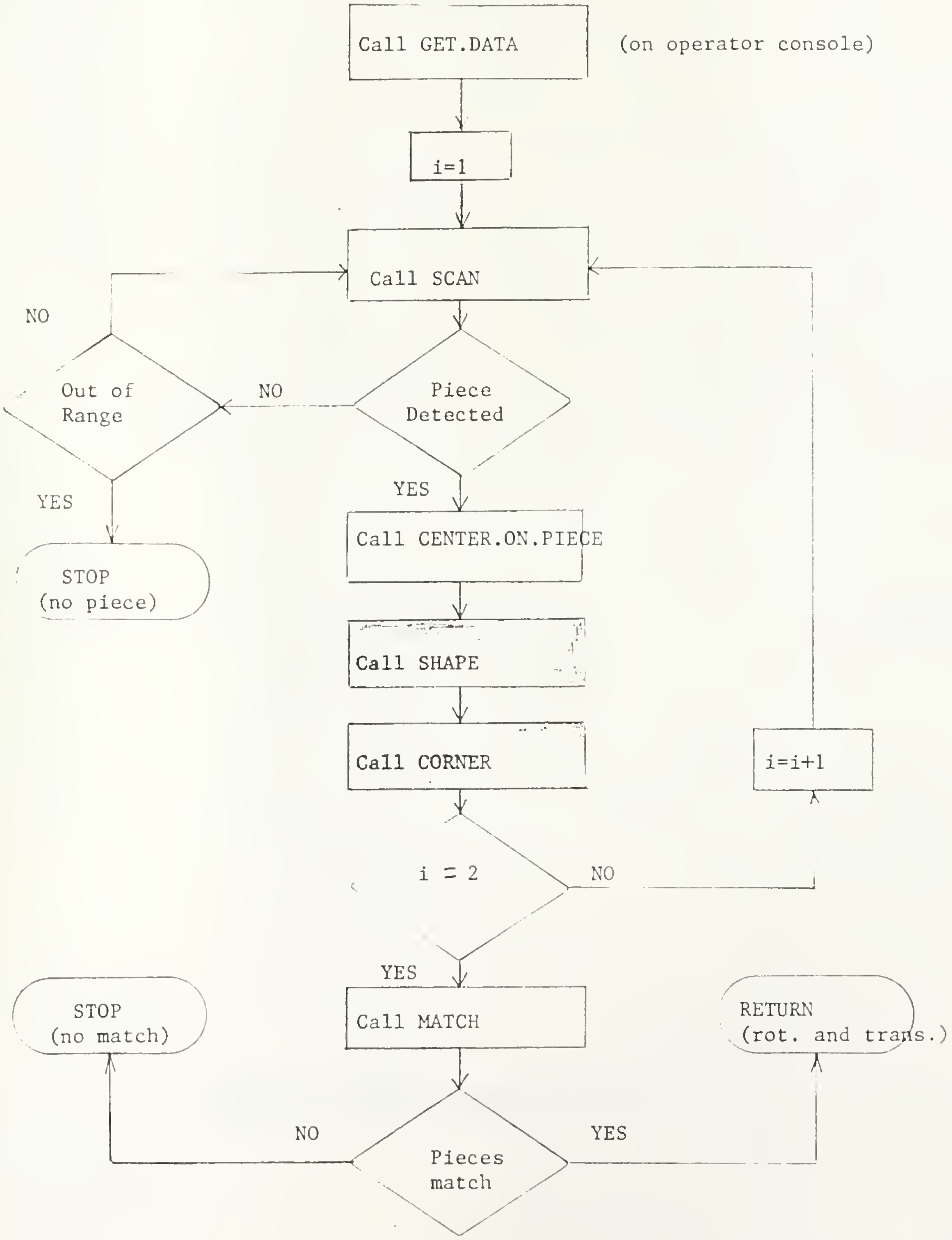

Fig. 4 Data aquisition program called from 7565 controler and running on host computer.

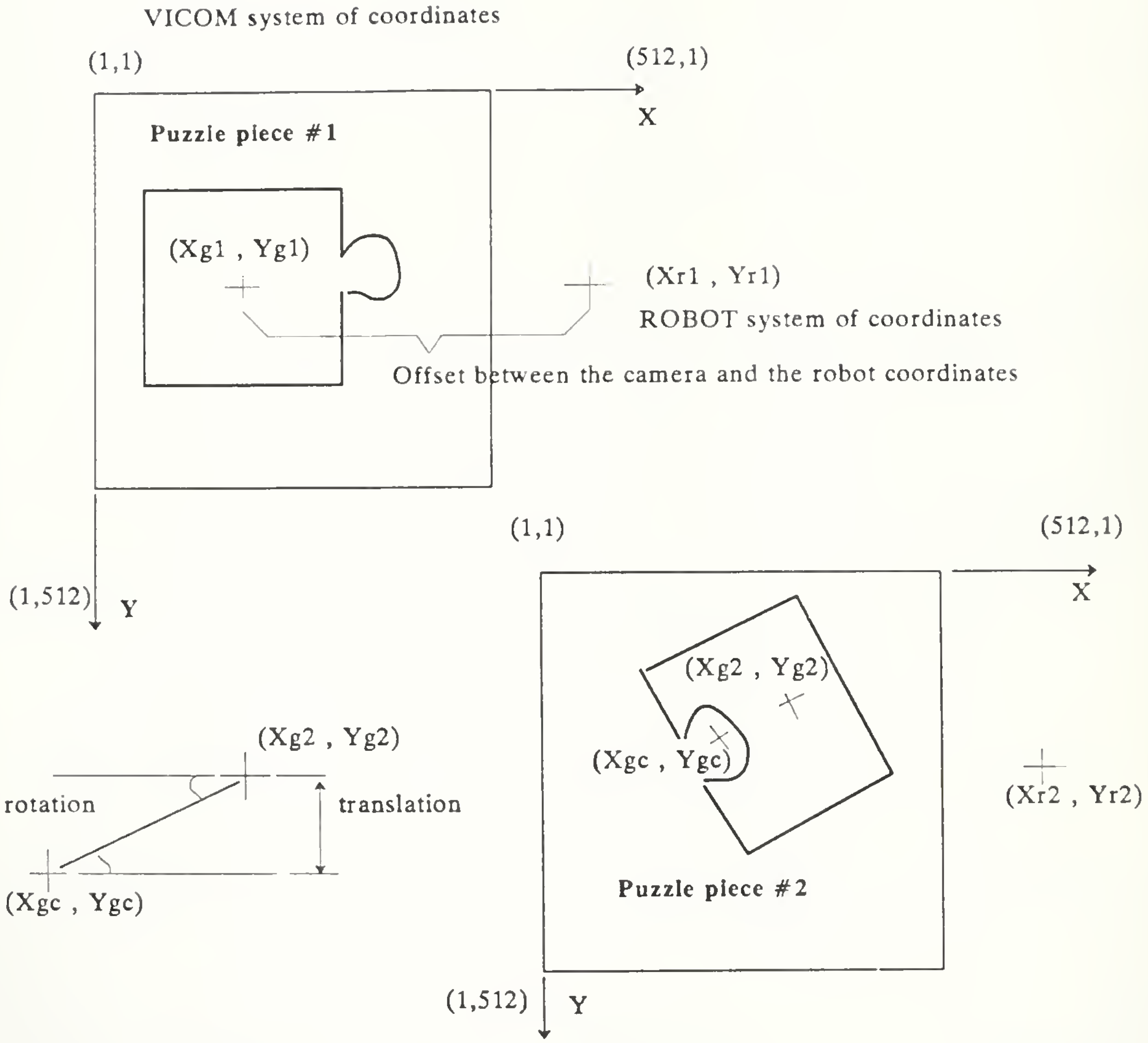

Fig. 5 Rotation and translation

No load on either sensor

```
[illegible]
SLS,SRS=75,0
SLS,SRS=75,0
SLS,SRS=75,0
SLS,SRS=75,15
SLS,SRS=75,0
SLS,SRS=75,0
SLS,SRS=75,0
SLS,SRS=7
[illegible]
```

500 g on left sensor

```
SLS,SRS= 483,-30
SLS,SRS= 483,-30
[illegible]
SLS,SRS= 483,-30
SLS,SRS= 483,-30
SLS,SRS= 483,-30
SLS,SRS= 483,-30
SLS,SRS= 483,-30
SLS,SRS= 498,-30
SLS,SRS= 483,-30
SLS,SRS= 483,-30
SLS,SRS= 483,-30
```

500 g on right sensor

```
[illegible]
SLS,SRS=0,-528
SLS,SRS=0,-528
SLS,SRS=15,-528
SLS,SRS=0,-528
SLS,SRS=0,-528
SLS,SRS=15,-528
SLS,SRS=0,-543
SLS,SRS=15,-528
SLS,SRS=0,-528
[illegible]
```

Fig.6 Force sensor indications with 15 g random"jumps"

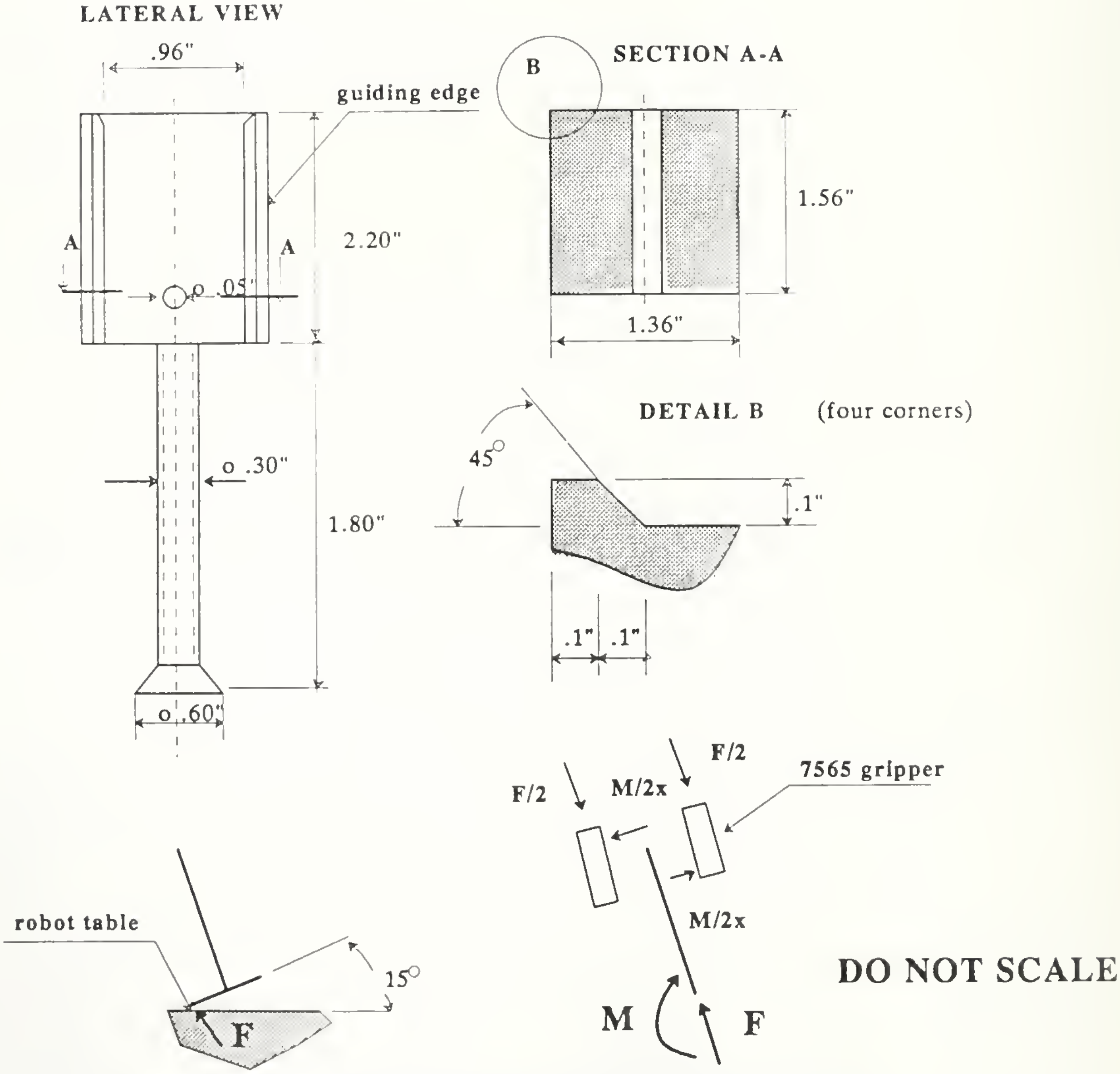

Fig. 7 Tentative robot tool design

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